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Directions in development of hydropower in the world, in Europe and Poland in the period 1995–2011

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A B S T R A C T

The paper presents, on the basis of international statistical data available and own research, the development of hydroenergetics in the world over the period 1995–2011.

The energy of flowing water for a number of centuries has been an alternative to energy from fossil fuels. Hydropower can be regarded as a relatively non-invasive to the surrounding environment especially in the form of small hydropower stations, what resulted in great popularity of this segment of the green-energy sector. Next the work presents, in tabular charts, graphs and descriptive parts, the levels of utilization of hydroelectric resources for individual continents and countries. Against this background, the paper describes Polish experiences and plans concerning hydropower.

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1. Introduction

Because of the unequal allocation of countries by different data sources, the geographic distribution used by the IGU (International Geographical Union) [1] and the WEC (World Energy Council) [2] was applied. Analysis was performed for the consecutive continents: Africa, America, Australia and Oceania, Asia and Europe. Data concerning particular continents is presented in Tables 2–7.

Unless otherwise stated, power values in all cases are given in GW, are given for conventional (dams) and run-of-the-river hydropower stations. Pumped storage plants, due to their structure and function for power systems were recognized as a separate category of hydroelectric power stations.

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Table 1
Regional hydropower technical potential in terms of annual generation and installed capacity, [4].

World region	Technical potential, annual generation TWh/yr	Technical potential, installed capacity 2009 GW
North America	1.659	388
Latin America	2.856	608
Europe	1.021	338
Africa	1.174	283
Asia	7.681	2.037
Australasia/Oceania	185	67
World	14.576	3.721

Hydropower is statistically the most common form of renewable energy and plays a very important role in the global energy production. According to the International Energy Agency (IEA) [3], the global generation of electricity from hydropower in 2010 was 3402.3 TWh, which accounted for almost 17% of total global energy production. The global technical potential is estimated at more than 16 400 TWh/year. The numerical values for the various continents are shown in Table 1.

Currently about 1/5 of world hydropower potential is used effectively. Countries with the most dynamic development of this sector of energetics use on average about 60% of its potential.

2. Hydropower in the world during 1995–2011

2.1. Introduction

Over the past few decades, decisions about the implementation of many projects related to hydropower encountered obstacles in the form of controversies. It was related to the impact of these facilities on the environment and the community residing in the location of the plant and its catchment. Balancing of gains and losses in this case is difficult and time consuming. When deciding on the role of hydropower in electricity supply one needs to take many factors into account. These include: protection of people and their property against floods and droughts, protection of environment (water, earth, air, and maintaining biodiversity), as well as economic aspect of ensuring and improving the existing standard of living of communities and extension of its legal protection for land expropriation intended to flooding. Often these factors are contradictory.

Hydropower is currently the most secure, efficient, reliable and flexible source of renewable energy, based on more than a hundred years of professional experience. Many hydropower plants in the world were built almost a hundred years ago, and these objects remain fully functional, like for example Hoover Dam (Nevada, USA) built in 1935, which with its 1.345 MW of installed capacity, in 1936 was the largest hydroelectric power station of this kind in the world. Thanks to a modernization carried out during 1986–1993 (including installation of two generators with a capacity of 2.4 MW each) installed capacity of the Hoover Dam rose to 2.080 MW (current status). Therefore, improvement of this technology can significantly extend the lifetime of power plant, which will translate to lower costs for energy production.

For a better and more authoritative look, in the chart (Fig. 1) the worldwide consumption of electricity from hydroelectric plants in the last few decades is presented.

An apparent tendency to increase consumption of electricity generated by broadly defined hydroenergetics, comprising the full range of its implementation, such as catchment-based hydropower plants or power stations utilizing sea currents.

Investment in large hydropower plants have contributed to the apparent increase in the world energy consumption, with more than 2-fold increase over the last 20 years.

In the analyzed period, the increase equaled 38.7%, which is due to turning to this source when seeking alternatives to electricity generation in Asian countries (mainly in China and India) and the Nordic countries. The distribution among the countries with the largest share in electricity production from water within this period is shown in Fig. 2.

The data presented clearly shows a dominance of China in global energy production, which is due to investments in enormous power plants.

Another important conclusion drawn from this graph is that the world's hydroelectric potential is unevenly used. Ten countries with the largest share of hydroenergy production account for about 2/3 of total world generation.

On the other hand, still a number of countries, use their hydroelectric potential very effectively and their generation capabilities are practically exhausted (Figs. 3 and 4).

2.2. Africa

Africa has relatively unfavorable climatic conditions for development of hydroenergetics. Therefore, despite potentially large area, African countries produce on average about 104 TWh of electricity [3,8] which represents 3.06% of global share.

Three countries with the largest installed capacity values (Table 2) during the period can be mentioned. The first one being Egypt with a complex of power plants on the Nile. The second country is Congo, running two power stations Inga on the Congo River, and planning their further development. The third on is Mozambique with the largest dam Cahora Bassa.

Considering energy production Egypt is the leader Chile Congo and Mozambique occupy the second and third positions respectively. Political stability has a strong impact on hydropower development in Africa, which directly impacts ongoing maintenance of facilities owned and planned investments [9]. Among the largest investments planned are the projects of building power plants Inga III (5 GW capacity planned) and Great Inga (39 GW). However, the high cost of these investments causes difficulties in obtaining of funding.

2.3. North and South America

The summary (Table 3) indicates that the largest share in electricity production in North America belongs to Canada and the United States, which have excellent geographical conditions for the development of hydroenergetics. They displayed an average share of 52.49% (Canada) and 43.15% (United States) in total production on the continent during the researched period. Since 1998, the U.S. has shown a decrease in electricity production, reaching a minimum value of 217 TWh in 2001. Global share of the countries mentioned above amounted in 2010 to 10.95% and 7.65%, respectively. The total is complemented by Mexico with the share of 4.37% in the continental production and 1.08% globally respectively.

Central and South America has an average global share of electricity production from hydro power of 28.58%. Between 1995 and 2010 the generation rose from 460 TWh to 686 TWh, giving an increase of more than 49.13%. The main reason is the increase in production in Brazil—a country with the largest share of energy production on the continent (58.15%). This resulted from an 66 GW increase in the installed capacity over the years 1995–2010, which represents 50.75% for the investigated area.

Table 2
The installed capacity of hydropower plants in Africa during the years 1995–2010, (gigawatts-GW) [3,5,6].

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Algeria	0.275	0.275	0.275	0.274	0.274	0.274	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.282
Angola	0.412	0.300	0.300	0.300	0.290	0.290	0.400	0.430	0.430	0.498	0.498	0.498	0.498	0.498	0.498	0.498
Benin	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Burkina Faso	0.030	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Burundi	0.043	0.043	0.043	0.043	0.043	0.043	0.030	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.051	0.051
Cameroon	0.723	0.723	0.723	0.723	0.725	0.725	0.800	0.805	0.805	0.805	0.805	0.805	0.805	0.805	0.805	0.805
Comoros	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Congo (Kinshasa)	2.515	2.515	2.515	2.515	2.440	2.440	2.515	2.535	2.469	2.410	2.410	2.410	2.410	2.442	2.442	2.442
Cote dIvoire (IvoryCoast)	0.895	0.895	0.895	0.895	0.614	0.614	0.614	0.614	0.604	0.604	0.606	0.606	0.606	0.606	0.604	0.604
Egypt	2.715	2.805	2.805	2.805	2.810	2.810	2.678	2.745	2.745	2.745	2.793	2.783	2.842	2.800	2.800	2.800
Ethiopia	0.377	0.378	0.378	0.378	0.398	0.451	0.451	0.635	0.635	0.669	0.669	0.669	0.669	0.784	0.969	1.85
Gabon	0.168	0.168	0.168	0.168	0.168	0.168	0.171	0.171	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.17
Ghana	1.072	1.072	1.072	1.072	1.072	1.072	1.072	1.182	1.180	1.198	1.198	1.180	1.180	1.180	1.180	1.18
Guinea	0.043	0.043	0.043	0.043	0.052	0.139	0.139	0.139	0.139	0.129	0.129	0.123	0.123	0.123	0.123	0.125
Kenya	0.604	0.604	0.603	0.600	0.675	0.675	0.675	0.677	0.677	0.677	0.677	0.680	0.680	0.747	0.747	0.761
Lesotho	0.000	0.000	0.075	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076
Madagascar	0.106	0.105	0.105	0.105	0.105	0.105	0.104	0.106	0.105	0.105	0.106	0.104	0.105	0.124	0.124	0.148
Malawi	0.164	0.219	0.221	0.221	0.221	0.221	0.283	0.283	0.283	0.283	0.283	0.283	0.283	0.283	0.283	0.286
Mali	0.050	0.050	0.050	0.050	0.050	0.090	0.114	0.150	0.155	0.155	0.155	0.155	0.155	0.155	0.157	0.157
Mauritania	0.069	0.079	0.079	0.082	0.082	0.082	0.082	0.095	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097
Mauritius	0.059	0.059	0.059	0.059	0.059	0.055	0.055	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
Morocco	0.939	1.006	1.093	1.205	1.205	1.205	1.300	1.273	1.273	1.498	1.500	1.265	1.265	1.265	1.284	1.284
Mozambique	2.109	2.109	2.109	2.109	2.180	2.180	2.184	2.136	2.136	2.136	2.165	2.165	2.250	2.179	2.179	2.179
Namibia	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249	0.249
Nigeria	2.341	1.938	1.938	1.938	1.938	1.938	1.938	1.938	1.938	1.938	1.938	1.938	1.938	1.938	1.938	1.938
Rwanda	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.026	0.026	0.026	0.026	0.026	0.027
Sierra Leone	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.054
Somalia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005	0.000	0.005	0.005	0.005	0.005	0.005
South Africa	0.610	0.610	0.668	0.668	0.668	0.668	0.661	0.661	0.661	0.661	0.661	0.661	0.661	0.661	0.661	0.661
Sudan	0.303	0.303	0.303	0.303	0.303	0.308	0.308	0.308	0.308	0.308	0.337	0.342	0.343	0.550	1.550	1.550
Swaziland	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.042	0.06
Tanzania	0.377	0.377	0.377	0.377	0.560	0.560	0.560	0.560	0.557	0.557	0.579	0.579	0.579	0.579	0.579	0.562
Togo	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.030	0.030	0.040	0.050	0.060	0.066	0.067	0.067	0.067
Tunisia	0.066	0.066	0.066	0.066	0.064	0.064	0.054	0.059	0.061	0.066	0.066	0.066	0.063	0.063	0.062	0.062
Uganda	0.186	0.186	0.261	0.261	0.276	0.276	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.315	0.315	0.352
Zambia	1.670	1.670	1.670	1.670	1.670	1.670	1.670	1.670	1.670	1.698	1.692	1.632	1.672	1.672	1.672	1.672
Zimbabwe	0.633	0.666	0.666	0.670	0.670	0.754	0.754	0.754	0.754	0.754	0.680	0.680	0.680	0.680	0.680	0.680
Other	0.243	0.243	0.243	0.246	0.244	0.244	0.244	0.245	0.245	0.245	0.245	0.245	0.243	0.272	0.272	0.228
Total	**20.20**	**19.94**	**20.24**	**20.36**	**20.37**	**20.63**	**20.95**	**21.31**	**21.24**	**21.56**	**21.61**	**21.30**	**21.49**	**21.86**	**23.08**	**24.06**

Table 3
The installed capacity of hydropower plants in North America during the years 1995–2010, (gigawatts-GW) [3,5,6].

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Canada	64.573	65.481	66.646	66.778	66.944	67.230	66.882	69.029	70.197	70.680	71.801	72.661	73.281	74.230	74.917	78.901
Mexico	9.329	10.034	10.034	9.703	9.634	9.634	9.636	9.635	9.650	10.565	10.598	10.800	11.577	11.471	11.530	11.338
USA	78.562	76.437	79.415	79.151	79.393	79.359	78.916	79.356	78.694	77.641	77.541	77.821	77.885	77.930	78.518	78.825
Total	**152.46**	**151.95**	**156.1**	**155.63**	**155.97**	**156.22**	**155.43**	**158.02**	**158.54**	**158.89**	**159.94**	**161.28**	**162.74**	**163.63**	**164.97**	**165.06**

Table 4
The installed capacity of hydropower plants in South America during the years 1995–2010, (gigawatts-GW) [3,5,6].

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Argentina	7.367	7.803	8.208	8.373	8.628	8.628	8.638	8.788	8.806	8.924	8.946	8.946	8.966	9.038	9.071	9.072
Belize	0.025	0.025	0.025	0.025	0.025	0.033	0.033	0.033	0.033	0.033	0.038	0.038	0.038	0.038	0.038	0.057
Bolivia	0.306	0.307	0.331	0.360	0.400	0.376	0.373	0.483	0.440	0.461	0.461	0.485	0.485	0.440	0.488	0.488
Brazil	51.311	53.428	54.970	56.759	58.997	61.063	62.523	65.311	67.793	68.999	70.858	73.434	76.871	77.870	79.291	80.703
Chile	3.599	4.107	4.169	4.350	4.336	4.450	4.447	4.473	4.484	5.167	5.169	5.175	5.302	5.387	5.407	5.467
Colombia	7.876	8.055	8.140	8.202	8.574	8.065	8.721	9.077	8.833	8.917	8.942	8.950	8.987	8.896	9.026	9.026
Costa Rica	0.878	0.981	1.054	1.053	1.110	1.225	1.226	1.271	1.296	1.304	1.304	1.411	1.412	1.518	1.532	1.554
Cuba	0.049	0.049	0.055	0.057	0.057	0.057	0.057	0.057	0.059	0.048	0.048	0.048	0.041	0.060	0.058	0.063
Dominicana	0.372	0.398	0.398	0.401	0.401	0.401	0.401	0.542	0.542	0.543	0.471	0.469	0.469	0.472	0.494	0.523
Ecuador	1.504	1.504	1.507	1.514	1.729	1.748	1.758	1.702	1.734	1.733	1.764	1.801	2.057	2.033	2.059	2.242
El Salvador	0.405	0.405	0.405	0.404	0.404	0.411	0.407	0.422	0.430	0.430	0.461	0.460	0.460	0.472	0.472	0.472
Guatemala	0.508	0.508	0.508	0.520	0.520	0.540	0.540	0.512	0.627	0.682	0.717	0.739	0.775	0.777	0.778	0.853
Haiti	0.062	0.055	0.055	0.062	0.062	0.062	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.062	0.054
Honduras	0.435	0.435	0.435	0.434	0.388	0.434	0.435	0.466	0.467	0.475	0.479	0.503	0.520	0.522	0.522	0.526
Jamaica	0.024	0.024	0.024	0.023	0.023	0.024	0.024	0.023	0.024	0.024	0.022	0.022	0.022	0.022	0.022	0.025
Nicaragua	0.106	0.106	0.103	0.103	0.103	0.103	0.103	0.104	0.104	0.105	0.105	0.105	0.104	0.105	0.105	0.105
Panama	0.551	0.551	0.551	0.551	0.553	0.613	0.613	0.701	0.833	0.833	0.907	0.847	0.793	0.869	0.879	0.936
Paraguay	6.870	7.108	7.390	7.390	7.390	7.390	7.410	7.410	7.410	7.410	7.410	8.110	8.130	8.130	8.810	8.810
Peru	2.499	2.493	2.512	2.572	2.673	2.860	2.965	2.996	3.032	3.056	3.207	3.214	3.234	3.242	3.273	3.438
Puerto Rico	0.085	0.085	0.085	0.085	0.100	0.100	0.100	0.100	0.100	0.100	0.138	0.142	0.164	0.156	0.156	0.156
Uruguay	1.521	1.521	1.534	1.534	1.534	1.534	1.534	1.538	1.538	1.538	1.538	1.538	1.538	1.538	1.538	1.538
Venezuela	10.675	12.234	13.026	13.224	13.215	13.215	13.207	12.491	12.491	13.864	14.597	14.597	14.597	14.567	14.622	14.623
Other	0.209	0.209	0.209	0.210	0.208	0.212	0.214	0.216	0.215	0.211	0.213	0.216	0.216	0.214	0.215	0.339
Total	**97.24**	**102.39**	**105.69**	**108.21**	**111.43**	**113.54**	**115.79**	**118.78**	**121.35**	**124.92**	**127.86**	**131.31**	**135.24**	**136.43**	**138.92**	**141.07**

Table 5
The installed capacity of hydropower plants in Australia and Oceania, data for 1995–2010, (gigawatts-GW) [3,5,6].

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Australia	7.624	7.665	7.704	7.704	7.704	7.711	7.711	7.770	7.788	7.781	7.795	7.795	7.827	7.814	7.808	8.048
Papua New Guinea	0.219	0.219	0.219	0.219	0.219	0.219	0.222	0.224	0.224	0.200	0.200	0.200	0.200	0.216	0.216	0.216
French Polynesia	0.020	0.020	0.046	0.046	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
New Caledonia	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078
New Zealand	5.259	5.120	5.158	5.159	5.390	5.193	5.260	5.341	5.347	5.345	5.347	5.346	5.348	5.376	5.378	5.250
Samoa	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Other	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Total	**13.22**	**13.12**	**13.23**	**13.23**	**13.46**	**13.27**	**13.34**	**13.48**	**13.51**	**13.47**	**13.49**	**13.49**	**13.52**	**13.55**	**13.55**	**13.66**

2.4. Australia and Oceania

Australia is the leader on the continent (Table 5), with more than 58.91% share in installed capacity. Second position is occupied by significantly smaller New Zealand with 38.43% share. It has, however, a much more favorable geographical conditions. The other island countries of the continent have a negligible share.

2.5. Asia

Asian countries (Table 6) account for over one fifth of world production of electricity from water. This is mainly thanks to China, where the increase of installed capacity during the years 1995–2010 reached an impressive value of 167 GW. This gave more than 3.7 fold increase in production to nearly 502 TWh. Only in the period 2005–2011 the production of hydroelectric power plants increased by 81%. China's share in the region and globally equals 49.71% and 20.98% respectively.

Next considerable countries, however having about four times lower values in relation to China, are India and Japan. Other, though much smaller in terms of production value, considerable countries in this ranking are Kyrgyzstan and Tajikistan.

Middle East region, abundant with and based primarily on oil, has a very small contribution in the production and hydropower installed capacity, although in both cases the trends show an increase.

2.6. Europe

In Europe, generation of electricity from water shows a continuous, albeit slow, upward trend, mainly thanks to new investments in the field of hydropower in the Nordic countries. Countries with the largest production during the years 1995–2011 were: Norway (an average of 120 TWh, which accounts for 21.81% for Europe and 3.54% for the world), Sweden (66 TWh on average, which represents 12.03% for Europe and 1.95% worldwide) and France (61 TWh on average, 11.08% for Europe and 1.80% for the world). The installed capacity in hydropower plants in Europe (Table 6) for the 1995–2010 period was on average at 160 GW, representing 21.56% of the world total. An upward trend in the value of installed capacity can be observed, mainly due to new hydroenergetic projects built in Nordic countries.

Poland has been showing a growth in production of electricity from water reaching an average of 2100 GWh, with the value of increase at 483 GWh observed during the period researched. It gives to Poland a place in the lower part of the table, with the average share of 0.38% in Europe and 0.08% in the world. The situation is similar considering installed capacity. Despite the general growth rate of 0.251 GW for the years 1995–2010, and the average at 0.837 GW, participation in European and global scale is small: 0.52% and 0.11%, respectively. Poland ranks not only far behind the Scandinavian countries, but also in relation to the closest, but a much better economically developed neighbor—Germany, which in terms of the average installed capacity of hydroelectric power surpasses Poland nearly five times.

3. Trends in the development of hydroenergetics in the world

3.1. Introduction

The value of installed capacity in hydropower plants tended to grow, from the level of 625.880 GW in 1995 to 917.544 GW in 2010, what gives an increase of 46.60%. Average global production of electricity from water power for the period presented equaled 2785 TWh, with a maximum value of 3402 TWh in 2010 and a minimum 2453 TWh in 1995, resulting in an increase by 38.68%.

In order to depict the trends in hydroenergetics Fig. 5 shows a graph showing electricity production in the world in the period 1995–2010 divided by continents.

The most significant increase in electricity production over the period was shown by Asia, mainly due to China. This country has in recent years ensured its leading position in the global share in hydroelectricity production. In the period 1995–2010 it increased almost two and a half times (220%). At the same time, China is still lagging behind when it comes to the use of its theoretical potential. At the same time USA's share has decreased.

Russia fares much less favorably. It is the largest country areawise, rich in possibilities of hydropower solutions utilization, due to its diversified topography, which might theoretically conduce using hydroenergetics. Its share in the global production on the level of 5% shows that much remains to be done on the subject. Russia, however, rich in natural resources, reluctantly looks for alternatives connected with the use of renewable energy sources.

3.2. Hydropower status for 2011

Hydropower is currently being actively used in approximately 150 countries [10]. The global increase in electricity generation from hydropower reached more than 5% in 2011, mainly thanks to using new resources and climate changes in China—more frequent occurrence of rainy weather. China increased its share in the global installed capacity by 16% in 2010, reaching 219 GW of capacity combined, which means an almost two fold growth when compared to 117 GW in 2005.

It is estimated that global installed capacity increased by 30 GW in 2010, what eventually that year gave an estimated value 917 GW.

When dividing by continents Asia dominates in the global share of installed capacity, followed by Europe, North and South America and Africa closing the ranking. Countries with the largest installed hydropower capacity are: Brazil, USA, Canada and Russia, with combined share in global installed hydropower capacity at 52%.

Table 6
The installed capacity of hydropower plants in Asia in the period 1995–2010, (gigawatts-GW) [3,5,6].

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Afghanistan	0.292	0.292	0.292	0.292	0.292	0.292	0.383	0.376	0.374	0.374	0.374	0.374	0.374	0.374	0.374	0.374
Armenia	1.012	1.012	1.012	1.012	1.012	1.165	1.165	1.166	1.170	1.024	1.027	1.052	1.068	1.080	1.102	1.162
Azerbaijan	0.783	0.695	0.690	0.680	0.790	0.953	0.953	0.992	0.992	1.020	1.025	1.025	1.025	1.025	1.025	0.987
Bangladesh	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230
Bhutan	0.342	0.342	0.342	0.342	0.345	0.414	0.430	0.430	0.445	0.445	0.468	1.488	1.488	1.488	1.488	1.488
Burma	0.317	0.328	0.328	0.328	0.340	0.340	0.390	0.390	0.405	0.425	0.480	0.530	0.560	0.580	0.600	0.800
Cambodia	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.012	0.012	0.013	0.013	0.013	0.013	0.013	0.013	0.013
China	52.134	55.587	59.730	65.065	72.971	79.352	83.006	86.075	94.896	105.242	117.388	128.570	145.260	171.500	196.800	219.000
Fiji	0.080	0.080	0.084	0.084	0.079	0.079	0.079	0.079	0.079	0.080	0.085	0.085	0.085	0.085	0.085	0.111
Philippines	2.258	2.300	2.303	2.304	2.304	2.304	2.520	2.518	2.867	3.217	3.222	3.257	3.289	3.291	3.291	3.400
Georgia	2.734	2.690	2.690	2.690	2.662	2.662	2.662	2.662	2.700	2.700	2.720	2.635	2.635	2.850	2.850	2.85
India	20.990	21.104	21.890	22.438	24.500	25.140	26.260	26.910	29.569	32.648	34.152	36.630	38.089	39.308	39.598	40.610
Indonesia	3.342	3.361	3.638	4.344	4.373	4.393	4.383	4.383	4.535	4.566	4.588	4.897	4.869	4.872	4.872	4.878
Iran	1.953	2.242	2.345	2.444	2.527	2.637	2.803	3.028	4.430	4.833	5.065	6.269	7.074	7.672	7.703	8.488
Iraq	0.910	0.910	0.910	0.910	0.910	0.910	0.910	0.600	0.700	1.810	1.862	2.225	2.273	2.514	2.514	2.514
Israel	0.005	0.005	0.005	0.006	0.007	0.007	0.007	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.007	0.007
Jordan	0.006	0.006	0.006	0.006	0.010	0.010	0.010	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Japan	21.171	21.222	21.277	21.477	21.555	22.019	21.621	21.697	22.006	22.048	22.133	22.199	21.824	21.852	21.784	22.362
Kazakhstan	2.233	2.230	2.230	2.230	2.032	2.032	2.260	2.260	2.263	2.263	2.217	2.217	2.217	2.217	2.217	2.217
Kyrgyzstan	2.797	2.797	2.797	2.949	2.949	2.949	2.969	2.969	2.910	2.910	2.910	2.910	2.910	2.910	2.910	2.910
Korea, North	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Korea, South	1.493	1.494	1.515	1.531	1.548	1.549	1.614	1.576	1.577	1.579	1.583	1.585	1.592	1.605	1.615	1.625
Laos	0.300	0.300	0.415	0.415	0.415	0.622	0.622	0.624	0.673	0.673	0.681	0.681	0.681	0.681	1.805	1.845
Lebanon	0.267	0.267	0.274	0.274	0.273	0.273	0.274	0.274	0.280	0.280	0.280	0.280	0.280	0.280	0.280	0.280
Malaysia	1.760	2.232	2.025	2.104	1.814	2.054	2.118	2.106	2.115	2.095	2.091	2.120	2.120	2.120	2.107	2.107
Nepal	0.262	0.262	0.262	0.262	0.334	0.334	0.384	0.584	0.584	0.575	0.554	0.560	0.560	0.660	0.660	0.664
Pakistan	4.826	4.826	4.826	4.826	4.826	5.010	5.039	5.046	6.491	6.497	6.499	6.479	6.480	6.481	6.555	6.592
Sri Lanka	1.137	1.137	1.137	1.140	1.143	1.150	1.161	1.172	1.247	1.281	1.293	1.326	1.316	1.357	1.357	1.391
Syria	0.900	1.000	1.000	1.100	1.100	1.200	1.500	1.520	1.520	1.520	1.505	1.505	1.505	1.151	1.250	0.900
Taiwan	1.581	1.687	1.687	1.820	1.820	1.820	1.820	1.909	1.909	1.910	1.910	1.910	1.921	1.937	1.937	1.977
Thailand	2.738	2.909	2.922	2.923	2.923	2.923	2.936	2.936	2.973	3.476	3.476	3.476	3.476	3.481	3.488	3.488
Tajikistan	4.054	4.054	4.054	4.054	4.054	4.054	4.054	4.054	4.054	4.054	4.037	4.037	4.037	4.037	4.037	4.037
Turkmenistan	0.004	0.004	0.004	0.004	0.004	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Turkey	9.863	9.935	10.102	10.307	10.537	11.175	11.673	12.241	12.579	12.645	12.906	13.063	13.395	13.829	14.553	15.831
Uzbekistan	1.690	1.690	1.690	1.690	1.690	1.690	1.710	1.710	1.710	1.710	1.710	1.710	1.710	1.710	1.710	1.730
Vietnam	2.880	2.892	2.892	2.892	2.862	3.292	4.128	4.155	4.155	4.155	4.155	4.580	5.500	5.500	5.500	5.500
Total	**152.35**	**157.13**	**162.61**	**170.18**	**180.24**	**190.05**	**197.09**	**201.7**	**217.47**	**233.32**	**247.66**	**264.94**	**284.87**	**313.71**	**341.33**	**367.38**

Table 7
The installed capacity of hydropower plants in Europe during the years 1995–2010, (gigawatts-GW) [3,5,6].

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Albania	1.445	1.445	1.445	1.445	1.445	1.445	1.445	1.445	1.445	1.445	1.432	1.432	1.432	1.450	1.450	1.461
Austria	7.733	7.795	7.961	7.872	8.076	7.711	7.740	7.603	7.643	7.650	7.703	7.720	7.878	7.883	8.067	10.600
Belgium	0.096	0.096	0.096	0.097	0.103	0.103	0.111	0.111	0.110	0.115	0.105	0.107	0.110	0.111	0.110	0.11
Belarus	0.007	0.007	0.007	0.007	0.007	0.007	0.008	0.010	0.010	0.012	0.012	0.012	0.013	0.013	0.013	
Bosnia and Herzegovina	1.219	1.219	1.219	1.624	1.983	1.983	1.993	2.380	2.380	2.380	2.380	2.411	2.411	2.411	2.411	2.117
Bulgaria	1.401	1.401	1.803	1.803	1.803	1.881	1.706	1.948	1.984	1.984	1.984	1.984	2.012	2.120	2.088	2.184
Croatia	1.781	1.785	1.785	1.785	1.785	1.785	1.785	1.775	1.783	1.790	1.804	1.804	1.782	1.782	1.799	1.848
Czech Republic	0.908	0.868	0.905	0.888	1.008	0.952	1.000	1.000	1.004	1.015	1.020	1.028	1.029	1.045	1.037	1.050
Denmark	0.010	0.010	0.010	0.011	0.011	0.010	0.011	0.011	0.011	0.011	0.011	0.009	0.009	0.009	0.009	0.009
Estonia	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.003	0.004	0.004	0.005	0.005	0.005	0.005	0.007	0.007
Faroe Islands	0.031	0.031	0.031	0.031	0.031	0.032	0.032	0.032	0.032	0.031	0.031	0.031	0.031	0.031	0.031	0.031
Finland	2.777	2.785	2.861	2.881	2.881	2.882	2.926	2.964	2.966	2.999	3.035	3.062	3.102	3.102	3.120	3.140
Former Serbia and Montenegro	2.250	2.250	2.250	2.250	2.296	2.296	2.296	2.296	2.296	2.206	2.206	–	–	–	–	–
Montenegro	–	–	–	–	–	–	–	–	–	–	–	0.658	0.658	0.658	0.658	0.658
Serbia	–	–	–	–	–	–	–	–	–	–	–	2.206	2.206	2.206	2.221	2.221
France	20.695	20.782	20.797	20.792	20.813	20.821	20.847	21.004	20.911	20.797	20.801	20.814	20.825	20.793	21.013	18.229
Germany	4.348	4.305	4.296	2.997	3.384	4.328	4.831	4.937	4.058	4.073	4.143	4.141	3.515	3.506	3.974	4.244
Greece	2.208	2.207	2.412	2.241	2.344	2.373	2.377	2.379	2.380	2.400	2.407	2.435	2.451	2.477	2.447	2.447
Hungary	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.054	0.049	0.049	0.049	0.049	0.051	0.053	0.053
Island	0.884	0.884	0.923	0.956	1.016	1.064	1.109	1.155	1.155	1.163	1.163	1.163	1.758	1.879	1.875	1.883
Ireland	0.227	0.232	0.233	0.233	0.236	0.236	0.238	0.240	0.240	0.240	0.234	0.234	0.234	0.239	0.238	0.238
Italy	12.964	12.999	13.060	13.058	13.417	13.389	13.456	13.557	13.703	13.789	13.890	13.528	13.573	13.732	13.827	13.976
Luxemburg	0.034	0.034	0.039	0.039	0.039	0.039	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
Latvia	1.521	1.521	1.487	1.517	1.523	1.523	1.565	1.565	1.537	1.536	1.536	1.536	1.536	1.536	1.536	1.536
Lithuania	0.108	0.108	0.108	0.108	0.112	0.112	0.113	0.103	0.109	0.110	0.117	0.117	0.115	0.115	0.115	0.115
Macedonia	0.423	0.423	0.434	0.434	0.434	0.434	0.436	0.436	0.448	0.516	0.540	0.528	0.528	0.528	0.528	0.573
Moldova	0.056	0.056	0.064	0.064	0.064	0.064	0.060	0.060	0.060	0.059	0.059	0.056	0.056	0.064	0.064	0.064
Netherlands	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
Norway	27.379	27.494	27.327	26.982	27.540	26.766	26.319	26.262	26.758	26.088	26.216	27.351	27.638	28.062	28.188	27.677
Poland	**0.681**	**0.681**	**0.681**	**0.808**	**0.813**	**0.817**	**0.868**	**0.841**	**0.867**	**0.876**	**0.915**	**0.925**	**0.922**	**0.929**	**0.932**	**0.936**
Portugal	3.848	3.867	3.877	3.940	3.930	3.929	3.963	3.990	3.991	4.315	4.497	4.017	4.023	4.026	4.051	4.064
Russia	44.000	44.100	43.900	43.700	44.100	43.900	44.700	44.828	45.221	45.531	45.835	46.062	46.804	46.804	47.000	46.873
Romania	6.011	6.038	6.074	6.081	6.082	6.120	6.122	6.242	6.248	6.279	6.289	6.282	6.334	6.367	6.427	6.382
Slovakia	1.525	1.655	1.664	1.682	1.684	1.685	1.586	1.586	1.588	1.602	1.596	1.597	1.599	1.632	1.571	1.600
Slovenia	0.757	0.734	0.734	0.861	0.846	0.846	0.839	0.983	0.974	0.974	0.979	1.010	1.018	1.028	1.070	1.074
Spain	11.689	11.793	11.596	11.537	11.802	12.672	12.744	15.550	15.525	12.820	12.873	12.971	13.025	13.104	13.158	13.188
Sweden	15.725	15.776	16.371	16.169	16.432	16.506	16.523	16.187	16.098	16.302	16.302	16.234	16.592	16.352	16.544	16.624
Switzerland	11.890	11.900	11.899	11.980	13.230	13.240	13.285	13.295	13.310	13.315	13.355	13.355	13.465	13.475	13.520	11.903
Ukraine	4.706	4.706	4.706	4.706	4.700	4.700	4.731	4.758	4.766	4.781	4.717	4.897	5.033	5.100	5.421	5.458
United Kingdom	1.432	1.455	1.488	1.475	1.477	1.485	1.629	1.590	1.486	1.499	1.501	1.514	1.525	1.630	1.645	1.649
Total	**192.86**	**193.53**	**194.63**	**193.14**	**197.53**	**198.22**	**199.52**	**203.25**	**203.23**	**200.83**	**201.81**	**203.36**	**205.37**	**206.33**	**208.29**	**206.293**

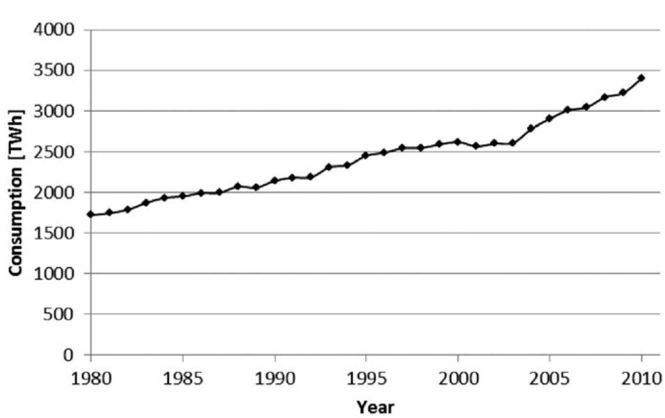


Fig. 1. World consumption of electricity produced in hydroelectric power plants (terawatt hours), [3,5,6].

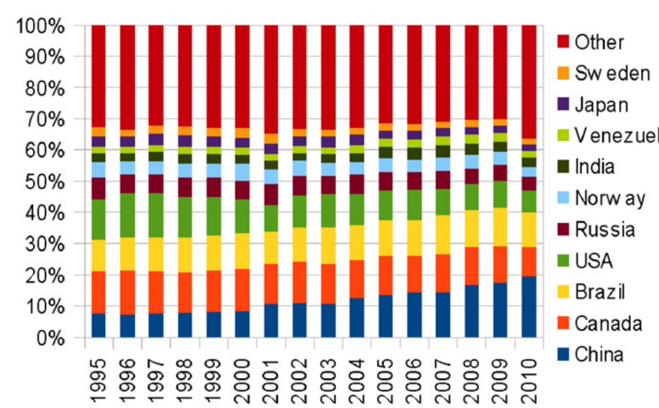


Fig. 2. Countries with the largest production of electricity in hydroelectric power plants, [3,5,6].

Brazil has the second place in the world, with the share of 8.8%, due to its 80.7 GW capacity, with a prospect to gain further 8.9 GW, which are expected to be gained from the new projects currently under construction.

The Canadian hydropower plants in 2010 generated 348 TWh of electricity. New installed capacity of 0.5 GW gave a total of 75.6 GW. It is estimated that around 11 GW will be installed in new projects, from which 1.3 GW will have been fully available by the end of 2012.

The USA, despite a slowdown caused by the economic crisis, has increased its share in installed capacity by 0.02 GW, showing a total of 79 GW in 2011, generating 325 TWh (from 233.6 TWh in 2009).

Russia has a total installed capacity of 55 GW, representing 20% of the national total output from all sources of energy.

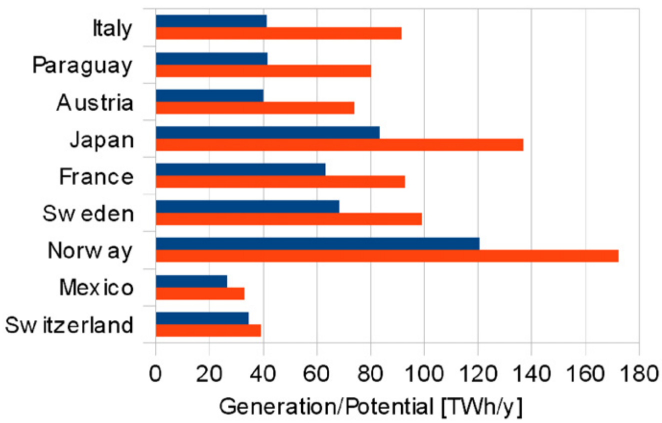


Fig. 3. Hydropower potential and generation in selected countries(terawatt hours per year), [3,5–7].

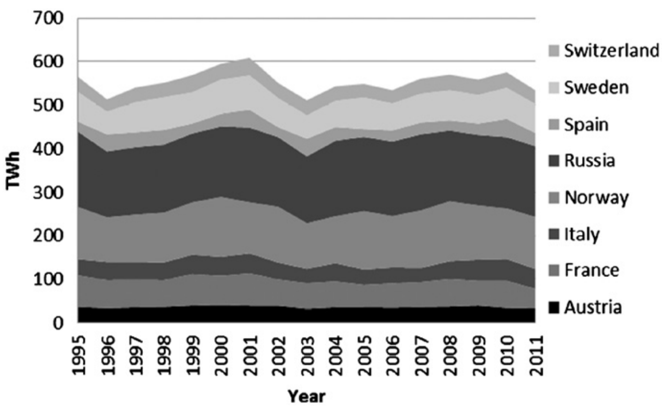


Fig. 4. Electricity generation in the selected European countries [3,5].

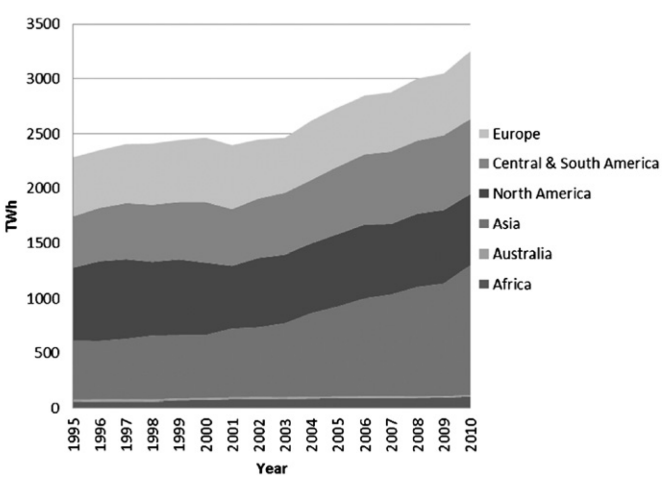


Fig. 5. Electricity generation on the individual continents [3,5].

Brazil and Canada generate 80% and 61%, respectively, of domestic electricity from water. Many African countries generates almost 100% of electricity (based on the network distribution), by hydropower.

The biggest hydropower projects completed in 2010 are two hydroelectric power plants called Nam Theun in Laos, with installed capacity of 1.1 GW. Furthermore Vietnam partially commenced a hydroenergetic project, which is supposed to be the largest hydroelectric power plant in South-East Asia, with the forecast installed capacity of 2.4 GW.

Many other countries pursue hydroenergetic projects of various sizes. In 2010 new power stations were completed in Ecuador (200 MW), Turkey (20 MW) and Uzbekistan (50 MW). Australia launched the first ever ion the continent power plant using treated communal and industrial wastewater for electricity production. The power station is located in the New South Wales is an extension of a sewage plant and generates energy using wastewater falling down a 60-m shaft. Having 4.5 MW of installed capacity, it offers a sufficient energy supply for the whole complex as well as external clients.

India ranked sixth considering the value of installed capacity with 40 GW (of which 37.4 is generated by large-scale units).

Brazil completed 53 investments in small hydroelectric facilities in 2010 (total 700 MW) and a further 149 objects have been authorized. Brazil is going to realize the two strategically significant projects in the Amazon region, with the 3.2 GW of installed capacity combined. Canada, Iran, Kazakhstan and Switzerland also have a significant amount of completed or planned small hydropower stations.

Asia (with China leading) and Latin America (where Basil dominates) are the most active regions regarding advancement in utilizing new projects in the field of hydroenergetics. Over the next five years China is planning further development of hydroenergetics by the next 140 GW. In cooperation with Iran, China intends to build a hydropower station—the largest dam in the world—with an estimated capacity of 1.5 GW, located in Zagros Mountains.

Countries of North America and Europe, in addition to the new facilities, focus on modernization of existing plants and further implementation of pumped-storage systems, where water is pumped from the bottom to the upper reservoir, later to be used for utilizing energy stored. In that case losses need to be taken into account as well as the stage when energy is used up, not generated. Despite these inconveniences interest in pumped-storage power stations is increasing, especially concerning economical aspect of electricity sales at times of peak demand for energy. Improvements in ability to regulate electroenergetic systems in particular countries are also important.

The vast majority of pumped storage plants are located in Europe, Japan and the United States. In 2010, the global installed power capacity increased by 4 GW of new (mainly due to new projects in Germany, Slovenia and Ukraine). It gave, in total, in 2010 the value of 136 GW of installed capacity for pump storage plants, which means an increase by 38 GW when compared with 2005. Further growth of 5 GW is forecast in coming years.

4. Development of hydropower in Europe during the years 1995–2011

4.1. Electricity generation

The first main document for the development of renewable energy in the European Union was the White Paper on RES from 1997, [11]. It assumed a doubling of the share of renewable energy from 6% to 12% of total gross energy consumption in Europe (EU-15) to 2010. Another piece of legislation was Directive 2001/77/EC on the promotion of energy from renewable sources. Its purpose was to achieve the objective of increasing the share of electricity from RES from 14% to 22% of gross electricity consumption by 2010.

Currently, the basic strategic document of the European Union's energy is contained in the so-called energy package from 2007, European energy policy [12]. It laid out an ambitious target for a reduction of 20% in 2020, compared to 1990, greenhouse



Fig. 6. Locations of hydropower stations in Poland, [27].

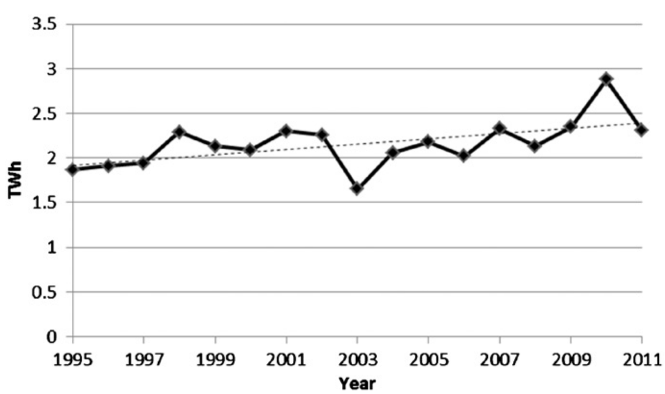


Fig. 7. Electricity generation in Poland [6].

gasses emission, a decrease of 20% (with respect to the variant "status quo") of primary energy consumption and achieve a 20% share of renewable (RES) in the primary energy. These objectives, applicable throughout the Community, are different for each country taking into account their specific features of infrastructure, the possibility of petrographical and achievements. Being an essential element of the "Energy Policy" action plan ("Roadmap") identifies a small hydropower (small hydro) as an important factor of "energy mix"—the structure of generation sources in power system [13].

In the 2009, the Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources has been established [14]. This Directive establishes a common framework for the use of energy from renewable sources in order to limit greenhouse gas emissions and to promote cleaner transport.

These regulations are essential for a large part of European countries and form the basis for the promotion of RES (including hydropower) development.

The situation of hydropower generation on the European continent in the years 1995–2011 is presented in Table 8 which shows values for output of flowing water plants in different European countries.

As can easily be seen, the leaders are the Scandinavian countries (Norway and Swede), thanks to favorable topography and abundance in natural watercourses. Their average share over the years 1995–2011 accounts for over 1/3 of the production of energy from hydropower in Europe. Whereas much larger Russia produced an average of 164 TWh, of which approximately 40% in the European, and the remaining 60% in the Asian part.

Most European countries covered in the chart have a small share in the global hydropower production. During 1995–2011 their share did not exceed 15.20 TWh, which is about 2.77% of the total European output.

4.2. New investments

The installed capacity of hydropower in Europe over the years 1995–2010 increased by 7.67%. It was mainly due to investments in new generation capacities. One of them is Goldisthal power station in Germany. Its construction started in September 1997,

Table 8
Electricity generation from hydropower in Europe between 1995–2011 (terawatt hour-TWh) [3,5,6].

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Albania	4.16	5.67	4.98	4.87	5.23	4.55	3.52	3.48	5.12	5.41	5.32	4.95	2.76	3.76	5.18	7.48	3.881
Austria	36.7	33.87	35.74	36.79	40.09	41.42	39.79	39.48	32.5	35.97	35.86	35.1	36.32	37.52	39.89	34.42	33.37
Belgium	0.34	0.24	0.3	0.39	0.34	0.46	0.44	0.36	0.25	0.31	0.29	0.36	0.39	0.41	0.33	0.31	0.197
Belarus	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Bosnia and Herzegovina	3.61	5.1	4.61	4.51	5.48	5.04	5.13	5.22	4.46	5.92	5.94	5.8	3.96	4.51	6.18	7.945	NA
Bulgaria	2.29	2.89	2.73	3.07	2.73	2.65	1.72	2.17	3	3.14	4.29	4.2	2.85	2.8	3.44	5.006	NA
Croatia	5.21	7.16	5.23	5.4	6.52	5.79	6.48	5.31	4.83	6.89	6.27	5.94	4.19	5.16	6.66	8.246	NA
Czech Republic	1.98	1.95	1.68	1.38	1.66	1.74	2.03	2.47	1.37	2	2.36	2.53	2.07	2	2.41	2.76	2.117
Denmark	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.02	0.02	0.017
Estonia	0	0	0	0	0	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.03	0.03	0.03	0.03
Faroe Islands	0.08	0.07	0.08	0.08	0.07	0.08	0.08	0.1	0.09	0.09	0.1	0.1	0.1	0.1	0.09	0.07	NA
Finland	12.8	11.74	12.12	14.9	12.65	14.51	13.07	10.67	9.5	14.92	13.65	11.38	14.04	16.94	12.56	12.75	12.353
Montenegro	–	–	–	–	–	–	–	–	–	–	–	1.75	1.64	1.53	2.04	2.749	NA
Serbia	–	–	–	–	–	–	–	–	–	–	–	10.86	9.94	9.47	10.14	11.772	NA
Former Serbia and Montenegro	12.07	14.27	12.64	12.76	13.24	11.88	12.33	11.63	9.75	11.01	11.91	–	–	–	–	–	–
France	72.2	64.43	63.15	61.48	71.83	66.47	73.89	59.99	58.57	59.28	51.23	55.6	57.52	63.14	56.57	62.17	44.65
Germany	21.56	21.74	17.18	17.04	19.45	21.52	22.51	22.89	19.07	20.87	19.39	19.73	20.69	20.73	18.47	18.81	18.18
Greece	3.49	4.31	3.84	3.68	4.55	3.66	2.08	2.77	4.72	4.63	4.97	5.81	2.57	3.28	5.32	6.55	3.793
Hungary	0.16	0.21	0.21	0.15	0.18	0.18	0.18	0.19	0.17	0.2	0.2	0.18	0.21	0.21	0.23	0.18	0.22
Island	4.64	4.72	5.16	5.57	5.99	6.29	6.51	6.91	7.02	7.06	6.95	7.22	8.31	12.3	12.16	12.47	12.38
Ireland	0.71	0.72	0.67	0.91	0.84	0.84	0.59	0.9	0.59	0.62	0.63	0.72	0.66	0.96	0.89	0.55	0.7
Italy	37.4	41.62	41.19	40.81	44.91	43.76	46.34	39.13	33.3	41.92	35.71	36.62	32.49	41.21	48.65	50.07	45.88
Luxemburg	0.09	0.06	0.08	0.11	0.08	0.12	0.12	0.1	0.08	0.1	0.09	0.11	0.12	0.13	0.11	0.11	0.06
Latvia	0.37	0.32	0.29	0.41	0.41	0.34	0.32	0.35	0.32	0.42	0.45	0.39	0.42	0.4	0.42	0.535	NA
Lithuania	2.91	1.84	2.92	2.99	2.73	2.79	2.81	2.44	2.24	3.08	3.29	2.67	2.71	3.08	3.43	3.48	NA
Macedonia	0.79	0.84	0.89	1.07	1.38	1.16	0.62	0.75	1.36	1.47	1.48	1.63	1	0.83	1.26	2.405	NA
Moldova	0.32	0.36	0.38	0.08	0.09	0.06	0.07	0.12	0.06	0.06	0.06	0.08	0.03	0.08	0.05	0.078	NA
Netherlands	0.09	0.08	0.09	0.11	0.09	0.14	0.12	0.11	0.07	0.09	0.09	0.11	0.11	0.1	0.1	0.10	0.056
Norway	120.13	102.56	108.93	114.24	120.24	137.53	117.12	128.12	104.56	107.77	134.31	118.16	132.32	137.63	124.89	116.3	119.6
Poland	**1.87**	**1.91**	**1.94**	**2.29**	**2.13**	**2.09**	**2.3**	**2.26**	**1.65**	**2.06**	**2.18**	**2.02**	**2.33**	**2.13**	**2.35**	**2.88**	**2.308**
Portugal	8.26	14.61	12.97	12.85	7.21	11.21	13.89	7.72	15.57	9.77	4.68	10.89	9.99	6.73	8.2	15.99	11.43
Russia	173.66	151.8	155.02	156.91	158.89	162.44	172.16	160.6	154.2	174.07	170.95	171.62	175.28	163.12	162.27	164.5	163.2
Romania	16.53	15.6	17.33	18.69	18.11	14.63	14.77	15.89	13.13	16.35	20.01	18.17	15.81	17.02	15.56	19.93	14.88
Slovakia	4.83	4.19	4.02	4.22	4.43	4.57	4.88	5.22	3.45	4.06	4.59	4.36	4.41	4	4.32	5.43	3.646
Slovenia	3.19	3.62	3.05	3.4	3.68	3.77	3.74	3.27	2.92	4.03	3.41	3.54	3.22	3.96	4.64	4.63	3.523
Spain	22.88	39.4	34.43	33.67	22.63	29.27	40.62	22.69	40.64	31.36	17.69	25.63	26.96	23.3	26.07	41.79	30.28
Sweden	67.42	51.22	68.37	74.25	70.97	77.8	78.27	65.7	53.01	59.52	72.08	61.11	65.5	68.38	65.19	70.60	65.60
Switzerland	34.82	28.46	33.7	33.14	39.6	36.47	40.9	34.86	34.47	33.41	30.91	30.65	34.9	35.68	35.37	35.70	31.81
Ukraine	9.85	8.55	9.76	15.76	14.18	11.16	11.91	9.53	9.15	11.64	12.24	12.76	10.04	11.27	11.73	12.83	NA
United Kingdom	4.79	3.36	4.13	5.07	5.28	5.04	4.02	4.74	3.2	4.8	4.87	4.55	5.04	5.12	5.21	3.55	5.637
Total	**692.22**	**649.5**	**669.86**	**693.11**	**707.95**	**731.45**	**745.37**	**678.17**	**634.41**	**684.37**	**688.5**	**677.33**	**690.94**	**709.05**	**702.44**	**745.32**	**NA**

and was completed and put into service in October 2004. It is the largest project of that kind in Germany and has an installed capacity of 4×265 MW (Francis turbines), two of which use a distinctive solution—asynchronous motors. Reservoir has a capacity of 12 million m^3 of water at full load and is able to cover a catchment area of 55 ha.

In Iceland the largest construction in this country was launched in 2007 and officially opened in 2009. It has six Francis turbines of 115 MW each. Dam has a height of 193 m, width 730 m. The rock structure of this type is the highest dam in Europe. The total length of tunnels hollowed for the execution and operation of the dam is 73 km. Power plant is located 600 m at the bottom of the shaft. Energy production is predicted to reach 4.600 GWh

In 1996, after almost thirty years of construction in the Czech Republic pumped-storage plant in the country was commissioned for use. It is situated in the valley of the river Desna Divoká. It has a total power of 650 MW, with two 325 MW turbines, the largest of this type in Central Europe. The difference in level between the upper and lower storage reservoir, amounts to about 510.3 m.

Austria can boast launching (in June 2008) a pumped-storage plant Kops-II in an unusual location. Power plant, shafts and drilling discharges were located entirely underground, without having destroyed the landscape. The upper tank (1800 m above sea-level) is connected to the lower tank (1000 m) placed in the valley via shafts, passing through the Tafamunt mountain. Three Pelton turbine generators with 150 MW each were installed there.

Based on the data we can say that despite the negative opinions of ecologist and controversies surrounding new investment placing quite remarkable energetic potential in large dams, they are a significant source of electricity for the population of the European continent.

5. Hydroenergetics development in Poland during the years 1995–2011

5.1. Hydroenergetic conditions of Poland

Poland is a country very poor in water [15]. The average annual precipitation is about 600 mm, which gives the third place from the end in Europe. Water resources are scarce, and the average Pole has only about 1.8 thousand m^3 per year on disposal. It is only 1/3 of the European average and 1/10 of the value for the

U.S. at the same time, the water consumption is very high, about 15 km^3 of water per year. Areas of significant deprivation of water cover approximately 60% of Polish territory. Existing reservoirs are able to accommodate only 3 km^3 of water, or about 5% of annual water outflow to the sea. There are also no major new projects which aggravates the situation of water-poor country.

The theoretical hydroelectric resources of Polish have been identified in the sixties on the basis on the methodology of the World Energy Council. They range in an average hydrological year around 23 TWh/year [16]. The technical resources of all the flowing water calculated by Hoffman [17] and Tyminski [18] are about 12 TWh/year, and the technical resources of SHP (hydropower plants up to 5 MW) are about 2 TWh/year. In total, this potential is about 14 TWh/year. The geographical distribution of this potential is as follows:

- Vistula river basin—9.3 TWh/year, including the River Vistula 6.2 TWh/year,
- Odra river basin—2.5 TWh/year, including the River Odra 1.8 TWh/year,
- Coastal basin—0.3 TWh/year,
- Small hydropower—2.0 TWh/year.

5.2. Historical development of hydro energetics in Poland

Initially, hydropower was used for the plants such as mills, paper mills, fulleries, and others. The first water mills appeared in Poland about the thirteenth century. Lasting for several hundred years the development of flour milling was halted during World War II. Post-war years is also a very difficult period for the operation of milling. In 1954 there were 6330 working small hydro plants (mills, saw mills, fullers, paper, etc.) that could be rebuilt. Fast industrialization, progressive electrification of rural areas, low energy prices and government policy did not favor using such small plants. As a result of politics conducted until 1960, most of the water mills have been liquidated or equipped with electric drives. Until the eighties, only 650 objects survived.

Electricity generation in hydropower plants on the Polish territory begun in 1910 on Radunia River near Gdansk, where first small hydropower plants were established in Straszyn and Rutki. However, the first professional hydropower plant (about 3.5 MW) was launched in Gródek, on the River Wda in 1923. In the thirties, preparations started for the construction of several major power plants on the rivers Dunajec, Soła and San. The Second World War halted the development of Polish hydropower. As a result of the postwar territorial changes Poland received dozens of hydroelectric plants located in the West. The largest were Pilchowice and Dychów on the river Bóbr. The total installed capacity in hydroelectric plants in Poland in 1946 amounted to 160 MW.

After the war, in the 50s the government adopted strategy to run the existing and suitable for repair large hydroelectric plants, with the restoration of their full functionality. Continuation of the construction of hydroelectric plants, interrupted by war and the implementation of projects and concepts prepared in the interwar period were also planned.

According to data from the Central Board of Energy, three years after the war, t80 hydropower plants with a capacity of 135 MW were restored. Construction of Porąbka hydroplant commenced in the late 40s. Over the next 20 years 16 hydroplants were restored or rebuilt after having been significantly destroyed, which resulted in gaining 212 MW of combined capacity.

The best period for development of hydropower in Poland were the years from 1968 to 1983, when a number of plants of various types: Solina, Żydowo, Porąbka-Zar, Włocławek and Żarnowiec were launched (Fig. 6).

Solina hydroelectric power plant (200 MW) is the highest dam in Poland—82 m, and boasts the largest storage reservoir with an area of 2100 ha. It was modernized in 2000–2003 years. Currently it has a capacity of 200 MW.

The beginning of the Żydowo power plant project dates back to the thirties of the twentieth century. The system connects a 6-m dam on the river Radew and two reserve tanks: the upper (Kamienno) and the lower (Kwiecko), with the difference in height between them equal 80 m. The power plant with total capacity of 150 MW was commissioned in 1970.

The largest hydropower plant in Poland is located in Wloclawek on the Vistula. It has the power of 160.2 MW (6 Kaplan turbines with a capacity of 26.7 MW each), and was launched in 1970. The total length of the crown of the dam is 650 m.

Porąbka-Żar power plant is the second biggest pumped-storage power plant in Poland. It was launched in 1979. It is equipped with four reversible Francis turbines of 125 MW each for the generating (turbine) mode, and 135 MW each for the pumping (motor) mode.

Pumped storage power plant Żarnowiec with capacity of 680 MW (4×170 MW) was launched in 1983. It is located on the lake Żarnowiec and is the largest hydropower plant in Poland regarding capacity.

Later there was a lull in the development of large hydropower. The only project was Niedzica pumped storage power plant launched in 1997. This is a complex of two hydroelectric power plants. The first one is the pumped storage power plant located in Niedzica with the capacity of 92.8 MW (2×46, 4 MW). The second facility is a run-of-the-river plant in Sromowce Wyżne power plant with the capacity of 4×520 kW. The dam was put to a great test, in conjunction with the largest flood in Poland.

Development of professional hydropower in Poland is illustrated in Table 9.

Since the early eighties, the government policy on the use of so-called small hydro has gradually changed. It was decided to stop further devastation of towers and support initiatives aimed at rebuilding ruined barrages and power stations.

Despite the stagnation in the construction of large hydropower there is a noticeable trend in the development of small hydroelectric plants, resulting both in general modernization and construction of new small hydropower plants.

5.3. Small hydropower in Poland

Considering the hydropower industry in terms of renewable energy sources it should be emphasized that despite the long tradition of hydropower use, the existing potential is used in a small degree, at 15%.

Poland currently has around 748 hydroelectric power plants [20], of which a tiny percentage are known as large objects with a power greater than 5 MW. Total installed capacity during the years 1970–2011 has doubled and now stands at about 955 MW, with a prospect to increase by the next 100 MW in future.

Considering using the potential so-called, small hydropower (SH) is regarded as an alternative to the large hydropower and territorially invasive projects. The local character of small hydro has several advantages, such as:

- they can be installed on small watercourses, with a wide variety of locations, and with thus a relatively fast process of implementation, from design to execution (estimated in theory for 2–3 years) with the widespread availability of materials and mastering the technology already known,
- smaller structural and mechanical complexity results in high durability and reliability,
- virtually unattended operation possible, using remote control of machinery from the main facility serving several small units,

Table 9
Large hydropower stations in Poland, [19,27].

No.	Name	River	Year of launch	Installed capacity [MW]	Type
1	Pilchowice	Bóbr	1912	7.9	Dam
2	Bielkowo	Redunia	1925	7.5	Dam
3	Bobrowice	Bóbr	1925	2.5	Dam
4	Żur	Wda	1929	9.0	Dam
5	Otmuchów	Nysa Kłodzka	1933	4.8	Dam
6	Rożnów	Dunajec	1942	50.0	Dam
7	Dychów	Bóbr	1951	79.5	Dam with pumped-storage
8	Porąbka	Soła	1953	12.6	Pumped-storage
9	Czchów	Dunajec	1954	8.0	Run-of-the-river
10	Brzeg Dolny	Odra	1958	9.7	Run-of-the-river
11	Koronowo	Brda	1960	26.0	Dam
12	Myczkowce	San	1961	8.3	Run-of-the-river
13	Dębe	Narew	1962	20.0	Run-of-the-river
14	Tresna	Soła	1967	21.0	Dam
15	Solina	San	1968	137.2	Dam with pumped-storage
16	Włocławek	Wisła	1970	162.0	Run-of-the-river
17	Żydowo	Radew	1971	152.0	Pumped-storage
18	Porąbka-Żar	Soła	1979	550.0	Pumped-storage
19	Żarnowiec	Piasnica	1982	716.0	Pumped-storage
20	Niedzica	Dunajec	1997	90.0	Run-of-the-river with pumped-storage

Table 10
Installed capacity of generating sources (megawatts-MW) [5].

Fuel/technology	2006	2010	2015	2020	2025	2030
Brown coal—CFB	8819	9177	9024	8184	10344	10884
Hard coal—CFB	15878	15796	15673	15012	11360	10703
Hard coal—CHP	4845	4950	5394	5658	5835	5807
Natural gas—CHP	704	710	810	873	964	1090
Natural gas—GTCC	0	0	400	600	1010	2240
Large hydro	853	853	853	853	853	853
Pumped-storage hydro	1406	1406	1406	1406	1406	1406
Nuclear	0	0	0	1600	3200	4800
Industrial coal—CHP	1516	1411	1416	1447	1514	1555
Industrial gas—CHP	51	50	63	79	85	92
Industrial other—CHP	671	730	834	882	896	910
Local gas	0	0	22	72	167	278
Small hydro	**69**	**107**	**192**	**282**	**298**	**298**
Wind	173	976	3396	6089	7564	7867
Biomass—CHP	25	40	196	623	958	1218
Biogas—CHP	33	74	328	802	1293	1379
Solar	0	0	0	2	16	32
TOTAL	**35043**	**36280**	**40007**	**44464**	**47763**	**51412**

- shortening of energy transfer (low cost) thanks to dispersed object location.

Of course, with the advantages, also noteworthy are the inconveniences slowing new projects down, of which the most important are:

- significant wear of dam facilities available, overgrowing reservoirs, silting of channels carrying water,
- long and complicated procedures.

When analyzing the problems of development of hydropower, one must distinguish between so-called high and low power hydroenergy. The border between them is determined by the size of the installed capacity of the object. In Europe, as the upper limit of small hydropower, the following installed capacity is indicated: 1.5 MW (Luxembourg, Sweden), 5.0 MW (Poland, Austria, Greece, Netherlands, Germany) and 10 MW (Belgium, Spain, Ireland, Portugal). Currently in Poland small hydropower plants (SHP) are operated that can be put into the following groups:

- about 300 SHP, private-owned, with an average installed capacity of 100 kW,
- about 110 SHP, state-owned, with an average power of 750 kW (electric utilities),
- about 5 SHP, public administration, with an average power of about 2500 kW (small retention).

Over the current decade construction of 860 damming projects is planned. About 400 out of them are able to be used as SHP. It is plausible that in a relatively short time the capacity of units existing and newly put into service reaches 290 MW and the total yearly energy production reaches 1180 GWh, which would account for 0.5% of the total energy production.

SHP hold a 0.6% share in electricity production in Poland, being the second biggest source of electricity supply from hydropower plants (30%), directly following large hydropower plants (with capacity exceeding 10 MW).

Despite big investment in the field of hydroenergetics made in Poland over the last 60 years and a slowly changing people's attitude towards using renewable energy sources, accompanied by new regulations concerning the necessity of implementing modern and environmentally-friendly solutions in energetic, the supremacy of traditional ways of gaining energy when considering the share in the total energy production is still clearly visible.

Considering the above, the current assumptions of energy policy of Poland established for the years coming up to 2030, look worrying. The guidelines do not assume increasing of energy production from these sources. On the one hand the policy assumes that "[there] will also be a significant increase in the use of hydropower, both small and large scale installations that interact in a meaningful way on the environment" [21,22]. Progonosed scenario and the value of installed capacity for different types of generation sources presented in Table 10.

In order to show the current trend in development of hydropower in Poland the distribution of electricity production in the last decade needs to be presented (Table 11, Fig. 7).

The largest share in electricity production belongs to large hydro, reaching the lowest value in 2008 (58.39%), the maximum in 2001 (66.84%), and with the average share over the years 2000–2010 on the level of 61.20%. The share of small hydropower (SHP) is the smallest and least dynamic, reaching a peak in 2005 (358.2 GWh).

Table 11
Electricity generation from hydropower in Poland in the years 2000–2011, [gigawatt hour-GWh], [23–26].

Installed capacity	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
< 1 MW	298.0	239.0	262.0	242.0	273.5	358.2	247.9	306.3	290.2	292.2	516.0	321.0
1–10 MW	422.0	532.0	585.0	431.0	616.9	504.2	566.6	658.1	605.4	627.9	667.2	638.0
> 10 MW	1386.0	1554.0	1432.0	998.0	1191.4	1338.7	1227.8	1387.7	1256.6	1455.0	1736.7	1388.0
Total	**2 106.0**	**2 325.0**	**2 279.0**	**1 671.0**	**2 081.7**	**2 201.1**	**2 042.3**	**2 352.1**	**2 152.2**	**2 375.1**	**2 919.9**	**2 331.0**

Table 12
Installed capacity of hydropower stations in Poland in the period 2000–2011, [megawatt-MW] [23–26].

Installed capacity	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
< 1 MW	57.0	76.0	60.0	63.0	77.0	72.0	72.0	72.0	74.0	77.0	78.0	90.0
1–10 MW	98.0	106.0	150.0	164.0	184.0	174.0	181.0	178.0	183.0	184.0	185.0	191.0
> 10 MW	662.0	686.0	631.0	640.0	615.0	669.0	672.0	672.0	672.0	672.0	673.0	674.0
Total	**817.0**	**868.0**	**841.0**	**867.0**	**876.0**	**915.0**	**925.0**	**922.0**	**929.0**	**933.0**	**936.0**	**955.0**

Capacity of hydroelectric power available in each group is presented in Table 12.

The remedy for the obstacles to the implementation of large hydropower is the introduction of distributed energy in the form of small hydro. With the implementation of the relevant legislative and economic support they can provide an excellent alternative and complement to the non-renewable energy on a local level (distributed generation).

6. Conclusions

Over the decades, the world's consumption of energy from hydroelectric power plants grew steadily, reaching in 2010 the value of 3402 TWh, which was caused by the implementation of a large amount of new projects. The largest percentage of energy consumption (21%) is shown by China.

Considering distribution divided by continents Asia dominates in the global share of installed capacity of hydropower plants. The second place belongs to Europe (mainly thanks to the Nordic countries) and North America (mostly Canada).

The implementation of many large hydro power plants was completed in Laos, China and Brazil, simultaneously focusing on the modernization of existing facilities could be observed in North America and Europe, where the vast majority of pumped storage is located.

In total, the world's installed capacity of pumped-storage plants equaled 136 GW in 2010, and over the next five years it is expected to increase by another 5 GW. Still, most countries do not use even a quarter of their theoretical potential. The exception being Norway, which Chile producing significant amounts of energy, relies its energetics on hydropower plants of different types, more often than not implementing various cutting-edge solutions not necessarily connected with projects having large-scale impact on the environment.

The biggest hydroenergy producers in Europe are Scandinavian countries: Norway and Sweden, whose combined share amounts to 1/3 of the production on the continent. An increasing trend in hydroenergy production could be observed towards the end of last decade.

In Poland during the researched period stagnation in the development of large objects was observed. The only exception is launched in 1997 Niedzica hydropower plant. Regression was caused by economic factors and unfavorable geographical and hydrological conditions for the construction of large power plants. There is also lack of appropriate legal instruments for the rapid deployment to the implementation of this branch of power generation. A noticeable trend is, however, the development of small objects in the so-called small hydropower, where a significant potential is believed to be found as well as an alternative offering effective and non-invasive utilization of hydroenergy.

Data on electricity production in Poland in 2010 showed a negligible share of hydropower in the energy balance at the level of 3%, with almost total domination of fossil fuels (96%).

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